INFLUENCE OF PLAIN AND BLENDED CEMENTS ON THE DURABILITY OF PINK LIME STONE CONCRETE IN MAGNESIUM SULPHATE AND SODIUM SULPHATE SOLUTIONS

Adel Kurdi

Department of Structural Engineering,
Faculty of Engineering, Alexandria University,
Alexandria, Egypt.

ABSTRACT

The effects of magnesium sulphate and sodium sulphate solutions on the durability of two plain cements and blended cements concrete specimens up to 360 days were investigated. The two types of plain cements were Egyptian Ordinary Portland cement (OPC) and Egyptian sulphate resisting portland cement (SRPC). The blended cements were silica fume (SF) from Egypt, blastfurnace slag cement (BFSC) from Egypt, and high slag blastfurnace cement (HSBC) from England (supplied by: Alexandria library project). In the silica fume blended cement, silica fume was used as 10 and 20 percent replacement by weight of ordinary portland cement. The Egyptian blastfurnace slag cement contained 35 percent blastfurnace slag and 65 percent OPC. The high slag blastfurnace cement contained 75 percent granulated blastfurnace slag and 25 percent OPC. In addition, the performance of silica fume cement containing 10 and 20 percent silica fume as a replacement of sulphate resisting portland cement was also evaluated.

The results of this investigation indicated that the strength reduction and the expansion strain of concrete specimens made with blended cements were less than those of concrete specimens made with plain cements when exposed to sodium sulphate solution up to 360 days. On exposure to magnesium sulphate solution for the same period of time, the strength reduction and expansion strain of blended cements were more than those of plain cement concrete specimens. No significant difference in strength reduction and expansion was observed between ordinary portland cement and sulphate resisting portland cement concrete specimens with water -cement ratio of 0.38 when exposed to magnesium sulphate or sodium sulphate solutions for 360 days. A similar trend was noticed in concrete specimens made with a water-cement ratio of 0.50.

Keywords: Durability, Blended cement, Sulphate attack, Expansion strain, Strength reduction

INTRODUCTION

Deterioration of concrete subjected to sulphate attack is a commonly observed phenomenon when structures are exposed to sulphate-bearing soils, ground water, and marine environments. Researches on concrete deterioration due to sulphate attack resulted in the development of sulphate resisting portland cement (SRPC) by modifying the chemical composition of ordinary portland cement [1]. Many laboratory and field studies have been carried out showing the good performance of this cement in producing highly resistant concrete against sulphate attack, particularly when exposed to moderate and strong sulphate environments , especially when the sulphate ions are associated with magnesium cations [2,3,4].

The lack in durability of ordinary portland cement and sulphate resisting portland cement exposed to sulphate environments has been partly attributed to the modifications in the chemical composition of these cements during the last four decades [5]. In order to achieve a rapid development of strength, the chemical composition of portland cements has undergone a significant increase in the ratio of C_3S / C_2S. High quantum of calcium hydroxide (CH) has been produced due to such modification. The increase in the C_3S content produces about 2.2 times of the calcium hydroxide than the same amount of C_2S. As the results of the increase in C_3S content in sulphate resisting portland cement, the concrete will be more vulnerable to sulphate attack for two reasons.

First, with the new chemical modification of modern cements, the concrete will achieve the same 28 _ days strength with high water to cement ratio resulting in a poor mix, an open pore structure, and permeable concrete. Second, a high amount of calcium hydroxide (CH) will be generate due to the increased amount of C_3S as a product of hydration. The calcium hydroxide provides the basicity to the pore solution , it has several damaging effects with regard to concrete durability subjected to sulphate attacks First, the permeability of concrete can be increased because the calcium hydroxide is leachable in water and in sulphate solutions. Second, gypsum can be produced due to reaction of calcium hydroxide with sulphate ions resulting in softening of cement paste. Third , the solubility of hydrated calcium aluminates (C-A-H) will be low, thereby making the sulphate reactions with these hydrates topochemical and expansive in nature [6]. Fourth, with the presence of calcium hydroxide, the ettringite formed is colloidal and results in expansive reaction, as hypothesized by Mehta [7].

The limitations on C_3A contents are not the final answer to the problem of concrete subjected to sulphate attack. This situation has encouraged the use of supplementary cementing materials or blended cement, such as fly ash, silica fume, and blastfurnace slag for increasing the resistance of concrete against sulphate attack. The superior performance of blended cement concretes compared to plain cement concretes subjected to sulphate deterioration is primarily attributed to the pozzolanic reaction, which can consume the calcium hydroxide, and to the dilution of C_3A phase due to reduction in the quantity of cement.

The aggressive actions of magnesium sulphate (MS) and sodium sulphate (NS) in concrete have been studied extensively by other workers [8,9]. Sulphate can attack different hydration products of portland cement with different intensities. The various reactions are described as follows:

Action on CH

Sodium sulphate and magnesium sulphate can react with calcium hydroxide to produce gypsum ($CS\text{-}H_2$), sodium hydroxide (NH) and magnesium hydroxide or brucite (MH).

$$CH + NS + 2H \text{ -------------- } (CS\text{-}H_2) + NH \quad (1)$$

$$CH + MS + 2H \text{ -------------- } (CS\text{-}H_2) + MH \quad (2)$$

The formation of gypsum is known to be destructive due to a volume increase upon transformation of calcium hydroxide to gypsum. Damage due to gypsum formation is limited to a softening action. On the other hand, gypsum formation may always be destructive and destruction appears only when gypsum forms in situ, topochemically [10].

Action on hydrated calcium aluminates, hydrated calcium sulphoaluminates, and unhydrated tricalcium aluminates (C_3A):

The gypsum in equation (1) and (2) can react with hydrated calcium aluminates, hydrated calcium sulphoaluminates and unhydrated tricalcium aluminates (C_3A) to form trisulphate hydrate or ettringite which is believed to be expansive by crystal growth and creat crystallization pressure mechanisms. Different mechanisms of reaction have been reported by other investigators [11].

Action on calcium silicate hydrate:

Magnesium sulphate attack has the greatest damaging effect on concretes. Because of the easy association of magnesium and calcium ions, magnesium sulphate reacts with calcium silicate hydrate gel (C-S-H) to produce gypsum. This in turn reacts with the calcium aluminates to produce more ettringite. The magnesium hydroxide and the silica hydrate formed from this reaction can react together to form a noncementitious product: magnesium silicate hydrate (MSH).

The decomposition of the cementitious calcium silicate hydrate gel to noncementitious magnesium silicate hydrate is only achieved by magnesium sulphate. Sodium sulphate cannot react with calcium silicate hydrate because sodium ions cannot replace the calcium ions in the calcium silicate hydrate gel.

RESEARCH SIGNIFICANCE

Deterioration of concrete structures located in sulphate bearing soils and ground water or exposed to marine environments has become widespread over much of Egypt. This paper reports the results of a laboratory test program conducted to evaluate the effect of magnesium sulphate and sodium sulphate environments on the performance of plain and blended concrete specimens. The performance of these cements were evaluated by measuring expansion and reduction in compressive strength.

EXPERIMENTAL PROGRAM

Materials

The materials used in this investigation included two types of Egyptian cements: Ordinary Portland cement (OPC) and sulphate resisting cement (SRPC). Three blended cements: silica fume (SF) from Egypt, blastfurnace slag cement (BFSC) from Egypt, and high slag blastfurnace cement (HSBC) from England (supplied by : Alexandria library project) were also used. In the silica fume blended cement, silica fume was used as 10 and 20 percent replacement by weight of ordinary portland cement. Egyptian blastfurnace slag cement contained 35 percent blastfurnace slag and 65 percent OPC. The high slag blastfurnace cement contained 75 percent granulated blastfurnace slag and 25 percent OPC. In addition, the performance of silica fume cement containing 10 and 20 percent silica fume as a replacement of sulphate resisting cement was also evaluated. The chemical composition of the cement and blending materials used in this investigation are shown in Table 1, while physical and mechanical properties of the cement and blending materials are shown in Table 2.

Pink lime stone was used as coarse aggregate and natural siliceous sand was used as fine aggregate in all mixtures. The unit weight, specific gravity and fineness modulus of sand were 1.75 t/m^3, 2.62, and 2.6 respectively. The maximum aggregate size of the graded pink lime stone was 19 mm., its unit weight, specific gravity and absorption were 1.52 t/m^3, 2.58 and 2.9 % respectively.

Mix proportions

A series of ten mixtures were prepared for durability studies on concrete specimens subjected to magnesium sulphate and sodium sulphate solutions. The mix proportions were determined according to the American concrete institute committee 211. Table (3) shows the mix proportions used in this study. Concrete mixtures containing silica fume used the same mix proportions as in plain cements (ordinary portland cement and sulphate resisting portland cement) except that 10 percent and 20 percent of the portland cement were replaced by an equal weight of silica fume. Concrete mixtures containing blastfurnace slag used the same mix proportions as in OPC except that 35 percent and 75 percent of the portland cement were replaced by an equal weight of blastfurnace slag. Due to difficulty in obtaining good dispersion with these admixtures, mixing times were increased and a melamine-based supperplasticizer was used to provide the same consistency. The values of supperplasticizer were obtained by trial and error from preliminary mixes. All the above concrete mixes were prepared having a water-cement ratio of 0.38. In addition two concrete mixes containing ordinary portland cement and sulphate resisting portland cement were prepared using water cement ratio of 0.50.

Test solutions

The test solutions consisted of 5 percent magnesium sulphate and 5 percent sodium sulphate solutions. The specimens were immersed in plastic tanks containing these solutions. The solutions were changed after 1, 2, 6, and 9 months of exposure. After 28 days of water curing, the specimens were divided into three equal series: the first, was kept as control in water, the second was exposed to 5 percent magnesium sulphate solution, and the third was exposed to 5 percent sodium sulphate solution until the time of testing. The reduction in compressive strength was tested on 100 mm.
cube concrete specimens after 28, 90, 180, and 360 days. The percentage of reduction in compressive strength was determined using the following relationship:

$$R = [(R1 - R2)/R1] \qquad (3)$$

Table 1 Chemical composition of cements and blending materials.

Constituent (weight)	OPC	SRPC	SF	BFSC	HSBC
Silicon oxide	21.1	21.9	95.9	25.6	32
Aluminum oxide	6.27	4.11	.1	9.3	8.29
Ferric oxide	2.63	4.42	.7	1.6	1.8
Calcium oxide	61.7	60.1	.1	54.1	48.65
Magnesium oxide	1.94	2.1	.2	4.5	6.04
Sulphur oxide	1.98	2.16	-	1.78	0.35
Loss on ignition	3.84	2.45	.8	2.81	1.94
Insoluble residue	0.86	1.15	-	1.22	0.51
Potassium oxide			.3		0.35
Sodium oxide			.2		0.2

OPC = Ordinary Portland Cement
SRPC = Sulphate Resisting Cement
SF = Silica Fume
BFS = Blastfurnace Slag
BFSC = Blast furnace Slag Cement (65% OPC + 35% BFS)
HSBC = High Slag Blastfurnace Cement (25% OPC + 75%% BFS)

Table 2 Physical and mechanical properties of cements and blending materials.

Property	OPC	SRPC	BFSC	HSBC
Setting time, min.				
Initial	160	185	155	220
Final	255	305	275	360
Compressive strength, N/mm^2				
3 days	23	20	12	14
7 days	29	28	21	24
28 days	37	-	-	45
Fineness % Retained on No.170 sieve	5.5	5.7	7.5	5
Soundness, mm. (Le chatelier)	1	1	1	0.5

where

R = The reduction in compressive strength, percent

R1 = The average compressive strength of three specimens cured in water

R2 = The average compressive strength of three specimens cured in the test solutions.

For measuring the expansion, the prismatic specimens 75x75x285 mm. were used.

RESULTS AND DISCUSSION

All concrete specimens were cured in tap water for 28 days prior to exposure to magnesium sulphate and sodium sulphate solutions. The results of strength reduction and expansion strain of plain and blended cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions up to 360 days are shown in Table 4 and Table 5 respectively.

Expansion strain

As shown in Table 4 and Table 5, the results regarding **ordinary portland cement** (w/c = 0.38) indicated lower expansion in concrete specimens placed in magnesium sulphate solution compared to that in concrete specimens placed in sodium sulphate solution. The expansion strains were .0317 and .0717 percent in concrete specimens exposed to magnesium and sodium sulphate solutions respectively. The expansion of **sulphate resisting portland cement** concrete specimens (w/c = 0.38) indicated a trend similar to that of ordinary portland cement concrete specimens. The expansion strains of sulphate resisting portland cement concrete specimens exposed to magnesium sulphate solution were less than that in concrete specimens exposed to sodium sulphate solution (0.0252 percent vs. 0.0780 percent).

Table 3 Mix proportion for plain and blended cement concretes.

Cement Types	Cement kg/m³	blended cement kg/m³	Water L/m³	Lime stone kg/m³	Sand kg/m³	C_{28} kg/cm²	Admix L/m³	slump mm.
OPC (w/c = 0.38)	400	0.0	152	1134	682	422	2	100
SRPC (w/c = 0.38)	400	0.0	152	1134	682	399	2	90
OPC + 10% SF	360	40	152	1134	682	471	2.5	90
OPC + 20% SF	320	80	152	1134	682	489	2.8	80
OPC + 35% BFS	260	140	152	1134	682	316	2.3	80
OPC + 75% BFS	100	300	152	1134	682	340	2.5	100
SRPC + 10% SF	360	40	152	1134	682	437	2.5	80
SRPC + 20% SF	320	80	152	1134	682	452	2.8	80
OPC (w/c = 0.5)	350	0.0	175	1134	682	385	-	100
SRPC (w/c = 0.5)	350	0.0	175	1134	682	348	-	90

C_{28} = Compressive strength of control concrete specimens after curing in tap water for 28 days

Table 4. Strength reduction and expansion strain in plain and blended cement concretes exposed to magnesium sulphate for 360 days.

Cement type	Strength reduction, percent				Expansion Percent			
	28 d.	90 d.	180 d.	360 d.	28 d.	90 d.	180 d.	360 d.
OPC (w/c = 0.38)	-2	7	16	21	.0135	.0166	.0235	.0317
SRPC (w/c = 0.38)	-3	4	11	17	.0122	.0160	.0218	.0252
OPC + 10% SF	3	8	18	23	.0166	.0225	.0399	.0565
OPC + 20% SF	5	8	19	29	.0177	.0241	.0421	.0590
OPC + 35% BFS	-2	13	24	37	.0146	.0280	.0345	.0467
OPC + 75% BFS	2	8	20	31	.0106	.0212	.0282	.0352
SRPC + 10% SF	1	6	15	22	.0099	.0206	.0266	.0425
SRPC + 20% SF	2	8	17	27	.0114	.0230	.0291	.0457
OPC (w/c = 0.5)	2	15	28	35	.0175	.0222	.0295	.0438
SRPC (w/c = 0.5)	1	13	25	32	.0152	.0201	.0273	.0370

Table 5 Strength reduction and expansion strain in plain and blended cement concretes exposed to sodium sulphate for 360 days.

Cement type	Strength reduction, percent				Expansion Percent			
	28 d.	90 d.	180 d.	360 d.	28 d.	90 d.	180 d.	360 d.
OPC (w/c = 0.38)	2	8	11	15	.0290	.0395	.0539	.0717
SRPC (w/c = 0.38)	2	7	9	13	.0390	.0541	.0685	.0780
OPC + 10% SF	-2	1	2	4	.0325	.0382	.0528	.0671
OPC + 20% SF	-4	1	3	5	.0333	.0393	.0542	.0692
OPC + 35% BFS	1	3	6	9	.0212	.0416	.0545	.0690
OPC + 75% BFS	1	2	5	7	.0292	.0311	.0435	.0608
SRPC + 10% SF	-2	1	2	3	.0366	.0458	.0515	.0658
SRPC + 20% SF	-2	1	1	2	.0377	.0482	.0539	.0686
OPC (w/c = 0.5)	4	10	20	25	.0345	.0471	.0625	.0862
SRPC (w/c = 0.5)	3	8	17	22	.0442	.0594	.0665	.0929

The expansion strains in **10 percent silica fume blended with ordinary portland cement** concrete specimens (w/c = 0.38) placed in magnesium sulphate solution were observed to be lower than that in concrete specimens placed in sodium sulphate solution. The expansion strains were .0565 and .0671 percent in concrete specimens exposed to magnesium and sodium sulphate solutions respectively. Similarly the expansion strain in **20 percent silica fume blended with ordinary portland cement** concrete specimens (w/c = 0.38) placed in magnesium sulphate solution was lower than that in concrete specimens placed in sodium sulphate solution (0.0590 vs. 0.0692 percent).

The expansion strain in **35 percent blastfurnace slag blended with ordinary portland cement** concrete specimens (w/c = 0.38) placed in magnesium sulphate solution was lower than that in concrete specimens placed in sodium sulphate solution. The expansion strains were .0467 and .0690 percent in concrete specimens exposed to magnesium and sodium sulphate solutions respectively.

Similarly the expansion strain in **75 percent blastfurnace slag blended with ordinary portland cement** concrete specimens (w/c = 0.38) placed in magnesium sulphate solution was lower than that in concrete specimens placed in sodium sulphate solution (0.0352 vs. 0.0608 percent).

The expansion strain in **10 percent silica fume blended with sulphate resisting portland cement** concrete specimens (w/c = 0.38) placed in magnesium sulphate solution was observed to be lower than that in concrete specimens placed in sodium sulphate solution. The expansion strains were .0425 and .0658 percent in concrete specimens exposed to magnesium and sodium sulphate solutions respectively. Similarly the expansion strain in **20 percent silica fume blended with sulphate resisting portland cement** concrete specimens (w/c = 0.38) placed in magnesium sulphate solution was lower than that in concrete specimens placed in sodium sulphate solution (0.0457 vs. 0.0686 percent).

Figures 1 and 2 give the expansion of plain and blended cement concrete specimens exposed to magnesium and sodium sulphate solutions respectively for 360 days. Zero expansion corresponds to the expansion of specimens after 28 days of initial curing in water. Control specimens cured in water up to 360 days did not show any expansion strain but normal swelling strain about 0.01 percent for all plain or blended cement concrete specimens. As shown from figure 1 and figure 2, no significant difference in expansion strain was observed between ordinary portland cement and sulphate resisting portland cement concrete specimens when exposed to magnesium sulphate or sodium sulphate solutions. On exposure to magnesium sulphate solution a higher expansion strain was observed regarding blended cement concrete specimens compared to plain cement concrete specimens. However in sodium sulphate solution, the expansion strain was higher in plain cement concrete specimens compared to blended cement concrete specimens. Tables 4 and 5 also display results of **ordinary portland cement and sulphate resisting portland cement concrete specimens using water-cement ratio of 0.50**. As in the case of water-cement ratio of 0.38, no significant difference in expansion strain was observed between ordinary portland cement and sulphate resisting portland cement concrete specimens when exposed to magnesium sulphate or sodium sulphate solutions. Figures 3 and 4 give the expansion strain of plain and blended cement concrete specimens exposed to magnesium and sodium sulphate solutions respectively for 90 days.

Strength reduction

The results of strength reduction in **ordinary portland cement** concrete specimens (w/c = 0.38) exposed to magnesium sulphate and sodium sulphate solutions up to 360 days are shown in Figure 5. The strength reduction in specimens exposed to sodium sulphate solution was slightly higher than that in concrete specimens exposed to magnesium sulphate solution up to about 100 days. After this period the reverse took place: the strength reduction was observed to be higher in concrete specimens exposed to magnesium sulphate solution than that in concrete specimens exposed to sodium sulphate solution. After 360 days of exposure the strength reduction in concrete specimens exposed to magnesium sulphate solution was about 1.4 times than that in concrete specimens exposed to sodium sulphate solution (strength reduction = 21 percent and 15 percent respectively).

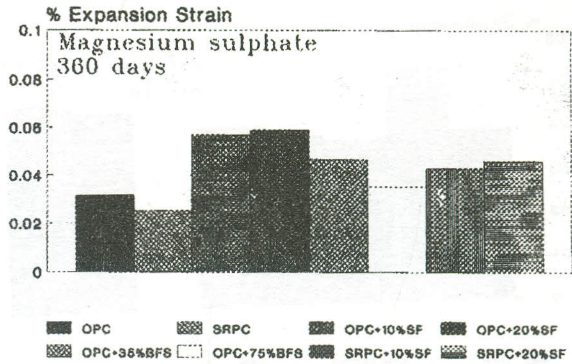

Figure 1 Expansion strain of plain and blended cement concrete specimens exposed to magnesium sulphate for 360 days.

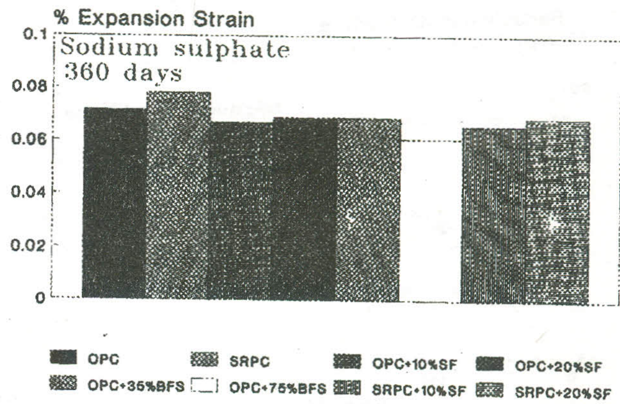

Figure 2 Expansion strain of plain and blended cement concrete specimens exposed to sodium sulphate for 360 days.

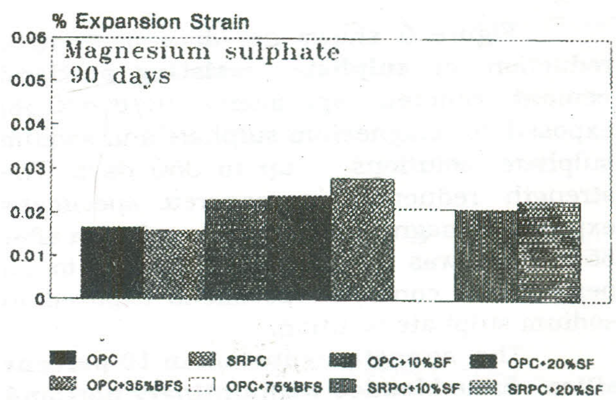

Figure 3 Expansion strain of plain and blended cement concrete specimens exposed to magnesium sulphate for 90 days.

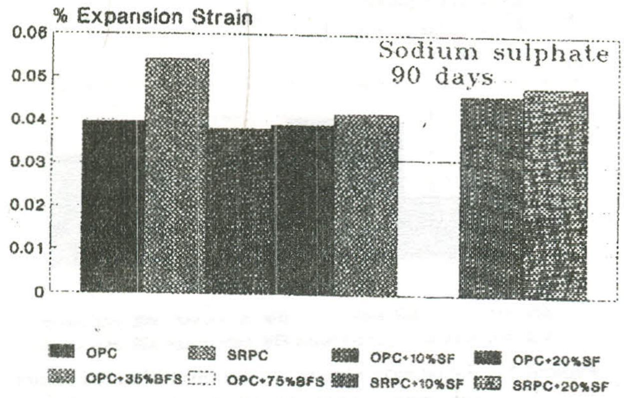

Figure 4 Expansion strain of plain and blended cement concrete specimens exposed to sodium sulphate for 90 days.

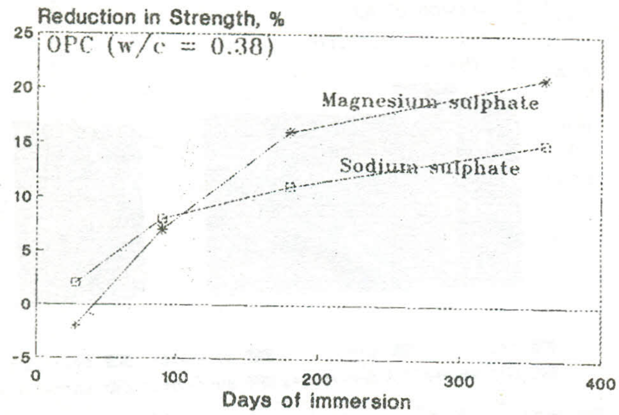

Figure 5 Strength reduction in ordinary portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

Figure 6 shows the data of strength reduction in **sulphate resisting portland cement** concrete specimens (w/c = 0.38) exposed to magnesium sulphate and sodium sulphate solutions up to 360 days. The strength reduction in concrete specimens exposed to magnesium sulphate solution after 360 days was 17 percent compared to 13 percent in concrete specimens exposed to sodium sulphate solution.

The strength reduction in **10 percent silica fume blended with ordinary portland cement** concrete specimens (w/c = 0.38) exposed to magnesium sulphate and sodium sulphate solutions up to 360 days is shown in Figure 7. The strength reduction in concrete specimens exposed to magnesium sulphate solution was nearly 6 times more than that in concrete specimens exposed to sodium sulphate solution (strength reduction = 23 percent and 4 percent respectively). Figure 8 shows that strength reduction in **20 percent silica fume blended with ordinary portland cement** concrete specimens (w/c = 0.38) exposed to magnesium sulphate was much higher than that in concrete specimens exposed to sodium sulphate solution. After 360 days, the strength reduction in concrete specimens exposed to magnesium sulphate solution was 29 percent compared to only 5 percent in concrete specimens exposed to sodium sulphate solution.

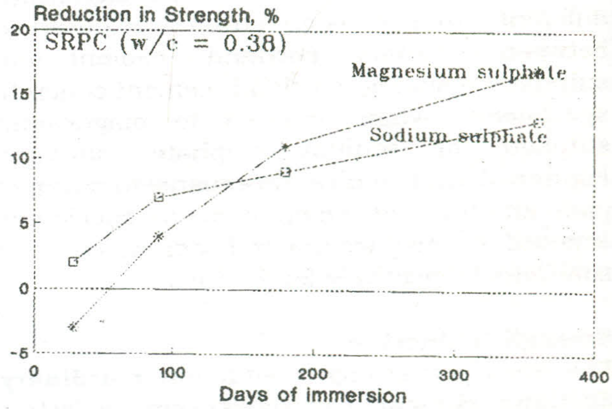

Figure 6 Strength reduction in sulphate resisting portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

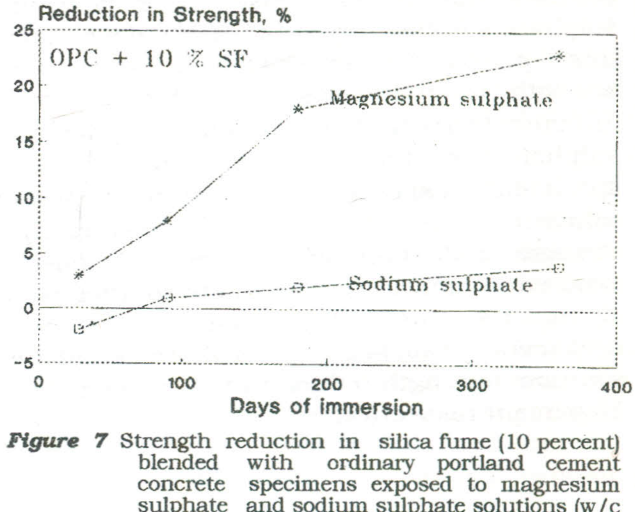

Figure 7 Strength reduction in silica fume (10 percent) blended with ordinary portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

The strength reduction in **35 percent blastfurnace slag blended with ordinary portland cement** concrete specimens (w/c = 0.38) placed in magnesium sulphate and sodium sulphate solutions up to 360 days is shown in Figure 9. The concrete specimens placed in magnesium sulphate and sodium sulphate solutions indicated strength reduction of 37 percent and 9 percent respectively after 360 days. Figure 10 shows the strength reduction in **75 percent blastfurnace slag blended with ordinary portland cement** concrete specimens (w/c = 0.38) exposed to magnesium sulphate and sodium sulphate solutions. The strength reduction was 31 percent in concrete specimens exposed to magnesium sulphate solution and 7 percent in concrete specimens exposed to sodium sulphate solution.

The data regarding strength reduction in **10 percent silica fume blended with sulphate resisting portland cement** concrete specimens (w/c = 0.38) exposed to magnesium sulphate and sodium sulphate solutions up to 360 days is shown in Figure 11. The strength reduction in concrete specimens exposed to magnesium sulphate and sodium sulphate solutions was 22 percent and 3 percent respectively. Figure 12 shows the strength reduction in **20 percent silica fume blended with sulphate resisting portland cement** concrete specimens (w/c = 0.38) exposed to magnesium sulphate and sodium sulphate solutions. The reduction in strength varied from 2 percent to 27 percent in concrete specimens placed in magnesium sulphate over 360 days, while it varied from -2 percent to 2 percent in concrete specimens placed in sodium sulphate solution for the same period of time.

The results of strength reduction in **ordinary portland cement** concrete specimens with water-cement ratio of 0.50 exposed to magnesium sulphate and sodium sulphate solutions up to 360 days are shown in Figure 13. The strength reduction was observed to be higher in concrete specimens exposed to magnesium sulphate solution than that in concrete specimens exposed to sodium sulphate solution. After 360 days of exposure the strength reduction in concrete specimens exposed to magnesium sulphate

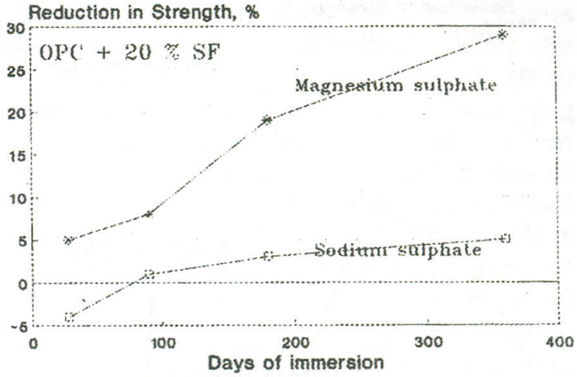

Figure 8 Strength reduction in silica fume (20 percent) blended with ordinary portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

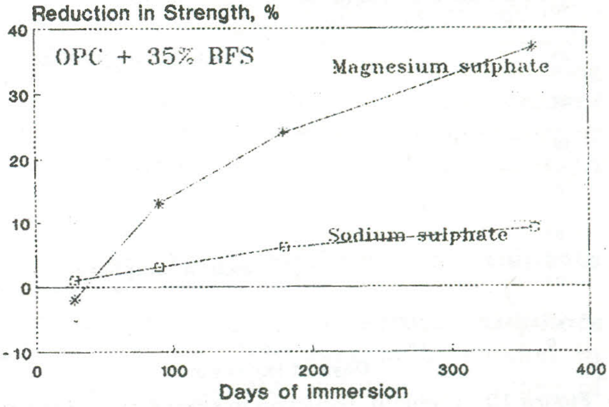

Figure 9 Strength reduction in blastfurnace slag (35 percent) blended with ordinary portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

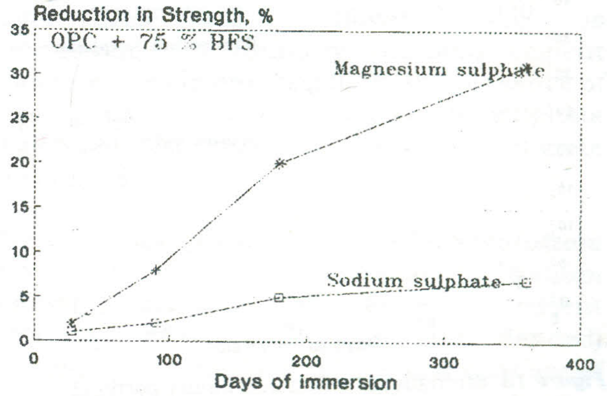

Figure 10 Strength reduction in blast furnace slag (75 percent) blended with ordinary portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

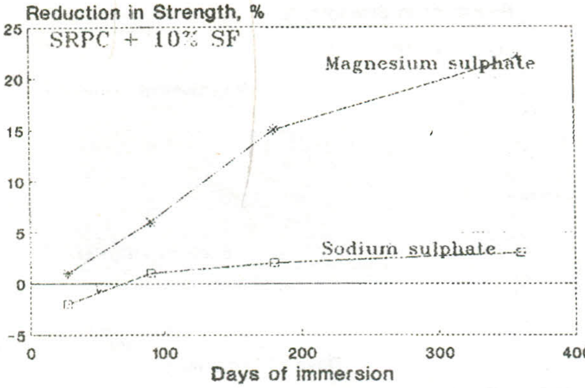

Figure 11 Strength reduction in silica fume (10 percent) blended with sulphate resisting portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

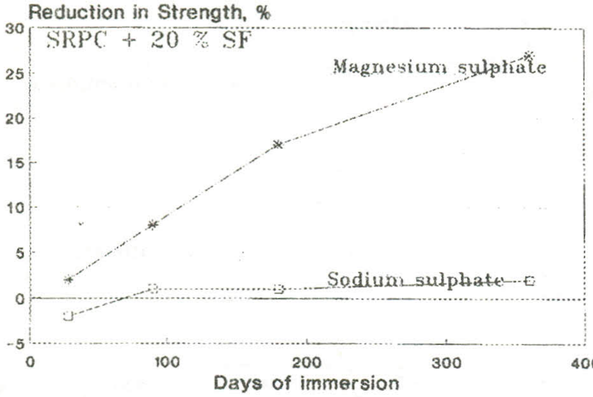

Figure 12 Strength reduction in silica fume (20 percent) blended with sulphate resisting portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.38).

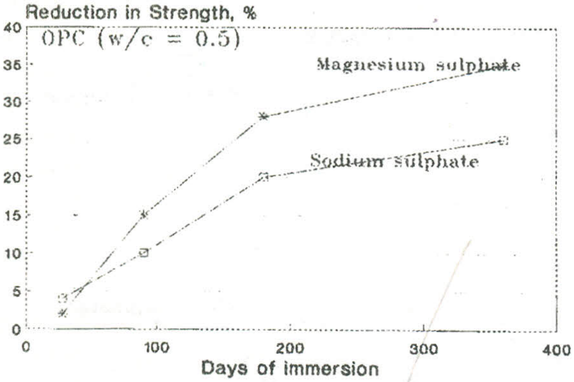

Figure 13 Strength reduction in ordinary portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.50).

and sodium sulphate solution was 35 percent and 25 percent respectively. In case of ordinary portland cement concrete specimens with water-cement ratio of 0.38 these values were 21 percent and 15 percent respectively (Figure 5).

Figure 14 shows the data of strength reduction in **sulphate resisting portland cement** concrete specimens with water-cement ratio of 0.50 exposed to magnesium sulphate and sodium sulphate solutions up to 360 days. The strength reduction was observed to be higher in concrete specimens exposed to magnesium sulphate solution than that in concrete specimens exposed to sodium sulphate solution. After 360 days of exposure the strengths reduction in concrete specimens exposed to magnesium sulphate and sodium sulphate solution were 32 percent and 22 percent respectively. In case of sulphate resisting portland cement concrete specimens with water-cement ratio of 0.38, these values were 17 percent and 13 percent respectively (Figure 6). Results shown in Figures 5, 6, 13, and 14 clearly indicate a beneficial effect of reducing the water-ratio regarding strength reduction.

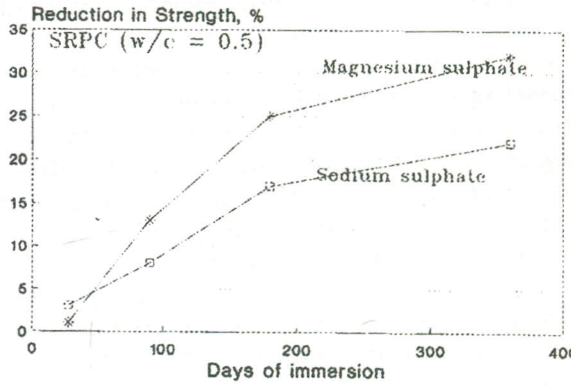

Figure 14 Strength reduction in sulphate resisting portland cement concrete specimens exposed to magnesium sulphate and sodium sulphate solutions (w/c = 0.50).

Effect of plain and blended cements on sulphate resistance

The performance of plain and blended cement concrete specimens in magnesium and sodium sulphate solutions can be evaluated from Table 4 and Table 5. No significant difference in strength reduction and expansion was observed between ordinary portland cement and sulphate resisting portland cement concrete specimens when exposed to magnesium or sodium sulphate solutions for 360 days.

In sodium sulphate solution after 360 days, the strength reduction in 10 percent silica fume blended with ordinary portland cement concrete specimens was 4 percent and in 20 percent silica fume blended with ordinary portland cement concrete specimens was 5 percent. In case of 35 and 75 percent blastfurnace slag blended with ordinary portland cement concrete specimens, these values were 9 and 7 percent respectively. The strength reduction of plain ordinary portland cement concrete specimens in sodium sulphate was high reaching a value of 15 percent. On the other hand, in magnesium sulphate solution, the strength reduction in 10 percent silica fume blended with ordinary portland cement concrete specimens was 23 percent and in 20 percent silica fume blended with ordinary portland cement concrete specimens was 29 percent. In case of 35 and 75 percent blastfurnace slag blended with ordinary portland cement concrete specimens, these values were 37 and 31 percent respectively. The strength reduction of plain ordinary portland cement concrete specimens was low having a value of 21 percent. As shown in Table 4 and Table 5, the results of plain and blended cements regarding expansion strain follow a pattern similar to that of strength reduction in both sodium sulphate and magnesium sulphate solutions. Thus, it can be concluded that, the addition of blended cements such as silica fume or blastfurnace slag to ordinary portland cement provided good durability of concrete specimens in sodium sulphate solution regarding strength reduction and expansion strain, while it gave the opposite effect in magnesium sulphate solution. From Tables 4 and 5, the same can be concluded for the addition of silica fume to sulphate resisting portland cement concrete specimens.

In magnesium sulphate solution after 360 days, the strengths reduction in 35 percent and 75 percent blastfurnace slag blended with ordinary portland cement concrete specimens were 37 percent and 31 percent respectively, while those values were 23 percent and 29 percent in 10 percent and 20 percent silica fume blended with ordinary portland cement concrete specimens respectively. In sodium sulphate solution the strength reduction values were 9, and 7 for 35 percent and 75 percent blastfurnace slag blended with ordinary portland cement concrete specimens and 4, and 5 for 10 percent and 20 percent silica fume blended with ordinary portland cement concrete specimens respectively. Thus it can be concluded that the strengths reduction in 10 percent and 20 percent silica fume blended with ordinary portland cement concrete specimens were lower than that in 35 percent and 75 percent blastfurnace slag blended with ordinary portland cement concrete specimens exposed to magnesium or sodium sulphate solutions. This study suggests a better performance of silica fume blended with ordinary portland cement concrete specimens compared to blastfurnace slag blended with ordinary portland cement concrete specimens exposed to magnesium or sodium sulphate solutions regarding strength reduction.

Effect of test solution on sulphate resistance

Performance in magnesium sulphate solution: After 360 days of immersion in magnesium sulphate solution, all types of cement concrete specimens (plain and blended) exhibited signs of deterioration, showing reduction in strength and increase of expansion strain. When considering reduction in strength, it is evident that the presence of silica fume and blastfurnace slag is detrimental to ordinary portland cement concrete specimens. Similarly the presence of silica fume is detrimental to sulphate resisting portland cement concrete specimens.

Performance in sodium sulphate solution: After 360 days of immersion in sodium sulphate solution, all types of cement concrete specimens (plain and blended) showed reduction in strength and increase of expansion strain. When considering reduction in strength, it is evident that the presence of silica fume and blastfurnace slag provided good durability to ordinary portland cement concrete specimens. Similarly the presence of silica fume provided good durability to sulphate resisting portland cement concrete specimens.

Role of water-cement ratio of plain cements on sulphate resistance

A comparison of the effect of the low (0.38) and the high (0.5) water-cement ratio for the two types of plain cement concrete specimens, ordinary portland cement and sulphate resisting portland cement, on the reduction strength and expansion strain, indicated that a significant benefit was observed regarding strength reduction in magnesium sulphate or sodium sulphate solutions due to the reduction of the water-cement ratio. For example in ordinary portland cement concrete specimens with water-cement ratios of 0.5 and 0.38 there was a strength reduction of 35 and 21 percent respectively after exposed to magnesium sulphate solution for 360 days. However, those values were 25 and 15 percent in sodium sulphate solution for the same period of time. Similarly the strength reduction in sulphate resisting portland cement concrete specimens with water-cement ratios of 0.5 and 0.38 was 32 and 17 percent respectively on exposure to magnesium sulphate solution for 360 days, while, those values were 22 and 13 percent in sodium sulphate solution. The above results show the beneficial effect of reducing the water-ratio regarding strength reduction.

CONCLUSIONS

- Higher reduction in strength was observed in plain cement concrete specimens compared to blended cement concrete specimens when exposed to sodium sulphate solution. However, on exposure to magnesium sulphate solution, the reduction in strength in plain cement concrete specimens was low compared to blended cement concrete specimens.
- Likewise, on exposure to sodium sulphate solution, a higher expansion was observed regarding plain cement concrete specimens compared to blended cement concrete specimens. When both types of concrete specimens were exposed to magnesium sulphate solution, the expansion was much lower in plain cement concrete specimens compared to blended cement concrete specimens.
- No significant difference in strength reduction and expansion was observed between ordinary portland cement concrete specimens and sulphate resisting portland cement concrete specimens when exposed to magnesium sulphate or sodium sulphate solutions.
- In order to asses the durability performance of plain and blended cement concretes in sulphate environments, we can rely on measuring expansion strain of concrete while exposing it to sodium sulphate solution rather than measuring reduction in strength. On the other hand, in magnesium sulphate solution, measuring strength reduction is superior to measuring expansion strain in assesing durability.

REFERENCES

[1] T. Thorvaldson, "Chemical aspects of the durability of cement products", Proceedings, 3rd international symposium on the chemistry of cement, London, pp. 436-466, 1952

[2] M. D. Cohen, and A. Bentur, "Durability of portland cement silica fume pastes in magnesium sulphate and sodium sulphate solutions", ACI Materials Journal, V.85, No.3, pp.148-157, 1988.

[3] D. Lawrence, "sulphate attack on concrete", Magazine of concrete Research, V.42, No.153, pp. 249-264, 1990.

[4] O. E. Gjorv, "Long time durability of concrete in seawater", ACI Materials Journal, Proceedings V.68, No. 1, pp.60-67, 1971.

[5] P. K. Mehta, "Durability of concrete-Fifty years of progress?", Durability of concrete, SP-126, V.1, American concrete institute, Detroit, pp.1-31, 1991.

[6] O. Al-Amoudi, M. Maslehuddin, and M. Saadi, "Effect of magnesium sulphate and sodium sulphate on the durability performance of plain and blended cements", ACI Materials Journal, jan.-Feb. 1995, pp.15-24.

[7] P. K. Mehta, "Mechanisms of expansion associated with ettringite formation", Cement and concrete research. V.3, No. 1, pp.1-6, 1973.

[8] F. M. Lea, "The chemistry of cement and concrete", 3rd edition, chemical publishing Co., New York, pp.727, 1971.

[9] G. L. Kalousek, and E. J. Benton, "Mechanism of seawater attack on cement paste", ACI Materials journal Proceedings V.67, No. 2, pp.187-192, 1970.

[10] W. C. Hanson, "attack on portland cement concrete by alkali soils and waters - A critical review", Highway Research Record No. 113, Highway Research Board, pp.1-32, 1966.

[11] M. D. Cohen, "Theories of expansion on sulphoaluminate-type expansive cement: schools of Thought", Cement and concrete research. V.13, No. 6, pp.809-818, 1983.